EO-1 Stray Light Analysis
Report No. 3

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MIT Lincoln Laboratory
244 Wood Street
Lexington, MA 02173

P.O. # AX-114413

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Prepared by:

Lambda Research Corporation
80 Taylor Street
P.O. Box 1400
Littleton, MA 01460-4400

Tel. (978) 486-0766
FAX (978) 486-0755

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1.   Summary

This study is a detailed follow-up to two previous studies concerning stray light in the EO-1 telescope (see EO-1 Stray Light Analysis Reports 1 and 2). Following coating of the EO-1 flight mirrors, the BRDF was measured by SSG, then re-measured by Schmitt Measurement Systems. The stray spectral radiance from the Stray Radiation Scene described in the LANDSAT 7 specification was recalculated using the Schmitt BRDF measurements and a simple spreadsheet calculation. This calculation assumes the Point Source Transmittance (PST) is rotationally symmetric, and does an integration over the Stray Radiation Scene.

To refine this estimate of stray radiance, ray-trace simulations were done using TracePro to better predict the PST. The PST was used to calculate the stray spectral radiance using a C++ computer program written for this purpose. The stray spectral radiance was computed by integrating over the LANDSAT 7 Stray Radiation Scene, weighed by the PST.

2.   Measured BRDFs and BRDF models

The measured BRDF data for mirrors M1, M2, M3, and F1 measured by Schmitt were curve-fitted using the ABg BSDF model to allow easier calculation of TIS, MTF degradation, and stray light, and for use in the TracePro simulations. This BSDF model has the form

$$BSDF(|\vec{\beta} - \vec{\beta}_0|) = \frac{A}{B + |\vec{\beta} - \vec{\beta}_0|^g},$$

where A, B, and g are fitting parameters. Per the Harvey-Shack BSDF model, $\vec{\beta}$ is the projection of the unit vector in the scattering direction onto the surface, and $\vec{\beta}_0$ is a projection of the specular direction unit vector onto the surface. This BSDF model has the advantage that it does not have a singularity at $|\vec{\beta} - \vec{\beta}_0| = 0$, as some other models do. It also adequately fits a wide variety of measured BSDFs. The fitted BRDF curves are shown in Appendix B.

3.   Predicted TIS, MTF Degradation, and Stray Light

Using these fitted BRDFs, we have computed the total integrated scatter (TIS), the MTF degradation, and the stray light according to the "Stray Radiation Scene." We have computed the contribution to each of these quantities from each mirror as well as the result for the whole system.

3.1   TIS

The TIS for each mirror was calculated by simply integrating the BRDF over a hemisphere,

$$TIS = \int_0^{2\pi} \int_0^{\pi/2} BRDF(\theta, \phi) \cos\theta \sin\theta \, d\theta \, d\phi.$$

Again, the BRDF has the form of the ABg BSDF model as described above. In this model, the BRDF scales as $1/\lambda^4$, and the angular dependence of the BRDF scales linearly with angle. Therefore, for a $1/\sin^2\theta$ dependence (i.e. $g = 2$), the BRDF will scale as $1/\lambda^4$ for small angles and $1/\lambda^{4-g}$ for large angles, and the TIS scales by a factor between $1/\lambda^4$ and $1/\lambda^{4-g}$.

3.2   MTF Degradation

The MTF degradation factor was calculated by first assuming that the scattered light causes a uniform haze when the instrument is presented with an extended scene. This in turn causes the wings of the point spread function to increase uniformly. Since the MTF is the Fourier transform of the PSF, and the Fourier transform of a constant value is a delta function, we expect the effect on the MTF to be addition of a delta function at zero frequency. Since the MTF is always normalized to the DC value, this has the effect of lowering the MTF uniformly, by a multiplicative factor, at all non-zero spatial frequencies. An MTF degradation factor can be computed as approximately

$$d = 1 - TIS .$$

The fact the scattered light is not uniform, but falls off with increasing angle, has little effect on this approximation, because it is nearly uniform compared to the Airy pattern, which falls off as $1/\theta^3$. This departure from uniformity is manifested as a slight broadening of the delta function, but the multiplicative factor is not affected.

This approximation will predict a worse degradation than will actually be observed for another reason: the scatter at large angles will miss the image plane. Furthermore, the mirrors are shaded from light incident at large angles by the baffles and by the finite field of view of the system. A more accurate calculation would integrate over a solid angle corresponding to the observable angle in object space as seen from each mirror.

3.3   Stray Light

The stray light was computed by first calculating the stray irradiance from the "stray radiation scene." The stray radiation scene consists of a small circular target region of low radiance surrounded by a large annular region of scene radiance. The stray light is specified as a ratio of the spectral radiance from this composite scene to the nominal full-scale spectral radiance for each band. We have calculated the stray spectral radiance as an equivalent scene radiance for direct comparison with the specification.

With a spectral radiance M_λ^{FOV} incident on the instrument from the target, the spectral irradiance focused on the detector by the instrument is

$$E_d^\lambda = M_\lambda^{FOV} \frac{\pi}{4F^2} ,$$

where F is the F-number of the system. A differential element of spectral irradiance incident on the instrument from a differential element of solid angle outside the target (i.e. from the stray radiation scene) is

$$dE_0^\lambda = M_\lambda^{SCENE} d\Omega ,$$

where is $d\Omega$ is the differential solid angle. The stray spectral irradiance resulting at the detector from the differential solid angle of the scene is

$$dE^{\lambda}_{stray} = PST \cdot dE^{\lambda}_{0},$$

where we model the PST as

$$PST = [f_1(\theta)S_1(\theta) + f_2(\theta)S_2(\theta) + f_3(\theta)S_3(\theta) + f_4(\theta)S_4(\theta)]\frac{\pi}{4F^2}.$$

Here the *f* functions are the BRDFs of the mirrors, and the *S* functions are the shading functions for each mirror. For this analysis, the shading functions are simply triangle-shaped functions of the form $S=1-(\sin\theta/\sin\theta_{max})$, and truncated to zero at angles larger than θ_{max}. The shading values are the same as used by Wally Wong of SSG, namely 26.6, 9.5, 9.5, and 4.75 degrees for mirrors M1-F1, respectively. The total stray spectral irradiance is the integral over the differential spectral irradiance,

$$E^{\lambda}_{stray} = \int_{stray\ scene} PST \cdot M^{SCENE}_{\lambda} d\Omega,$$

which expands to

$$E^{\lambda}_{stray} = \frac{\pi}{4F^2} M^{SCENE}_{\lambda} \int_{stray\ scene} [f_1(\theta)S_1(\theta) + f_2(\theta)S_2(\theta) + f_3(\theta)S_3(\theta) + f_4(\theta)S_4(\theta)]d\Omega.$$

Here we have taken the (annular) angular dependence of the scene spectral radiance out of M and put it into the integration limits, allowing us to treat M as a constant. Finally, there is a contribution to the stray light due to the target itself. This is identical in form to the scene stray light, except that the target spectral radiance is used and the integral is performed over the circular region comprising the inside of the stray radiation scene (i.e., the target). The sum of these two stray light terms give the total stray spectral irradiance. Noting that the signal light collected by the instrument from the target is

$$E^{\lambda}_{d} = M^{FOV}_{\lambda}\frac{\pi}{4F^2},$$

we can get an expression for the equivalent stray spectral radiance,

$$M^{stray\ eqivalent}_{\lambda} = E^{\lambda}_{stray}\frac{4F^2}{\pi} = M^{SCENE}_{\lambda} \int_{stray\ scene}(\sum f_i S_i)d\Omega \quad + \quad M^{FOV}_{\lambda} \int_{t\arg et}(\sum f_i S_i)d\Omega.$$

The *target* integration region is the small 768 µr diameter hole in the annular stray radiation scene. It has a small contribution to the stray light, but we include it for the sake of completeness. The above integrals have been calculated for each of the 8 bands in the LANDSAT 7 System Specification Revision K (July 1997).

3.4   Results

The results of the above calculations are summarized in the tables below. Table 1 shows the predicted TIS and MTF degradation factor due to each mirror, and the composite or system predictions.

Table 1 Predicted TIS and MTF degradation factors

BAND	TIS - Schmitt BRDF data					MTF Multiplier - from Schmitt BRDF data				
	M1	M2	M3	F1	Composite	M1	M2	M3	F1	Composite
PAN	0.0321	0.0014	0.0270	0.0042	0.0647	0.9679	0.9986	0.9730	0.9958	0.9353
1	0.0756	0.0034	0.0647	0.0113	0.1551	0.9244	0.9966	0.9353	0.9887	0.8449
2	0.0533	0.0023	0.0454	0.0076	0.1086	0.9467	0.9977	0.9546	0.9924	0.8914
3	0.0377	0.0016	0.0319	0.0051	0.0764	0.9623	0.9984	0.9681	0.9949	0.9236
4	0.0222	0.0009	0.0185	0.0028	0.0444	0.9778	0.9991	0.9815	0.9972	0.9556
5	0.0048	0.0002	0.0038	0.0005	0.0093	0.9952	0.9998	0.9962	0.9995	0.9907
6	5.4E-05	1.8E-06	1.9E-05	1.7E-06	7.7E-05	0.9999	1.0000	1.0000	1.0000	0.9999
7	0.0025	0.0001	0.0018	0.0002	0.0046	0.9975	0.9999	0.9982	0.9998	0.9954

Table 2 shows the equivalent stray spectral radiance for all eight bands. The results are expressed both as equivalent spectral radiance values and as a percentage of the saturation signal for all eight bands in the LANDSAT 7 Spec. Rev. K, and for both gain settings. The numbers in this table compare directly with the 2% requirement stated in the specification. In Table 3, the contribution for each mirror is shown. Clearly, the stray light from M1 is the major contributor in all bands, due to its high BRDF and relatively full illumination by the stray radiation scene. These predictions are probably slightly pessimistic. A more accurate calculation could be done by simulating the telescope with a ray tracing program such as TracePro to generate a three-dimensional PST, then integrating over the stray radiation scene.

Table 2 Equivalent stray spectral radiance from the Stray Radiation Scene.

Band	Low gain spectral radiance	High gain spectral radiance	Stray Spectral Radiance	percent of lo gain	percent of hi gain	Spectral Radiance FOV	Spectral Radiance Scene	bFOV	bGAP	bSCENE	represent. wavelength
PAN	23.50	15.63	**1.20**	5.12%	7.70%	2.285	44.05	0.000256	0.000768	0.436	0.71
1	28.57	19.00	**4.03**	14.09%	21.19%	4.000	57.32	0.000256	0.000768	0.436	0.48
2	29.13	19.37	**2.64**	9.06%	13.63%	3.000	55.17	0.000256	0.000768	0.436	0.57
3	22.50	14.96	**1.58**	7.02%	10.56%	2.167	48.31	0.000256	0.000768	0.436	0.66
4	22.50	14.96	**0.65**	2.89%	4.34%	1.375	35.72	0.000256	0.000768	0.436	0.84
5	4.73	3.15	**0.043**	0.92%	1.38%	0.400	12.97	0.000256	0.000768	0.436	1.65
6 (cond 1)	1.50E-03	7.70E-04	**2.0E-08**	0.0013%	0.0026%	8.50E-04	8.50E-04	0.000682	0.000682	0.436	11.45
6 (cond 2)	1.50E-03	7.70E-04	**3.3E-08**	0.0022%	0.0043%	8.50E-04	1.42E-03	0.000682	0.000682	0.436	11.45
7	1.67	1.11	**0.0094**	0.56%	0.85%	0.170	5.93	0.000256	0.000768	0.436	2.22

Table 3 Contributions of each mirror to the equivalent stray spectral radiance.

BAND	Stray Spectral Radiance by Mirror- Schmitt data				% contribution by mirror			
	M1	M2	M3	F1	M1	M2	M3	F1
PAN	0.8887	0.0215	0.2821	0.0121	73.79%	1.78%	23.42%	1.00%
1	2.7991	0.0710	1.1015	0.0544	69.53%	1.76%	27.36%	1.35%
2	1.8794	0.0468	0.6821	0.0317	71.19%	1.77%	25.84%	1.20%
3	1.1527	0.0281	0.3828	0.0168	72.94%	1.78%	24.22%	1.06%
4	0.4923	0.0117	0.1399	0.0056	75.79%	1.79%	21.54%	0.87%
5	0.0366	0.0008	0.0058	0.0002	84.47%	1.83%	13.26%	0.44%
6 (cond 1)	1.92E-08	3.24E-10	2.40E-10	7.00E-12	97.11%	1.64%	1.21%	0.04%
6 (cond 2)	3.20E-08	5.41E-10	4.00E-10	1.17E-11	97.11%	1.64%	1.21%	0.04%
7	8.27E-03	1.73E-04	9.30E-04	2.91E-05	87.96%	1.84%	9.89%	0.31%

4.   TracePro Simulations and Stray Radiation Scene Integration

In order to refine the estimates of stray light by more accurately modeling the shading functions (view factors) of the mirrors, the EO-1 instrument was simulated using TracePro, a Monte Carlo ray-tracing program developed and marketed by Lambda Research. In TracePro, rays or photons are traced through an optical system and the interactions of these rays with optical surfaces are modeled according to probability distributions. The probability distributions are used to model the directions in which light scatters. Variance reduction techniques are used to improve the efficiency of the Monte Carlo process. These variance reduction techniques include ray splitting and importance sampling. In ray splitting, a ray may be split into several components when it strikes a surface. For example, reflected, refracted, absorbed, and scattered components may be produced. In importance sampling, a ray may be selected to go along an unlikely path that is of interest to the user (e.g., toward the detector or an image of the detector) thereby increasing the probability to one, and the flux of the ray component is renormalized to compensate for the increased probability.

TracePro has its Monte Carlo roots in the GUERAP stray light analysis program which has been used for almost 30 years to analyze stray light in a large number of aerospace optical systems.

4.1   TracePro Model

The TracePro model used for the simulations was based on a previous model of the instrument developed under contract to SSG. This earlier model included the GIS spectrometer, which was deleted from the model for this study. The model was then modified to include the correct location of baffle edges in the as-built flight unit. The shape of the entrance port was also modified to match drawings supplied by MITLL, while the M1, M3, and F1 mirror shapes were left as rectangular approximations to the true shapes. The latches for the instrument cover were added, as was the stop on the secondary mirror. The ABg models of BRDF that were fitted to the 0.6328 μm data measured by Schmitt Measurement Systems were applied to the mirrors. A small image surface of radius 0.01 mm was defined at six degrees off axis in the cross-track direction. Finally, importance sampling was defined for the mirrors, stop, baffles and instrument structure to enhance sampling to this small image. An isometric view of the completed model is shown in Figure 1. The TracePro coordinate system is also shown in Figure 1, with the z axis pointing to the right along the optical axis, the y axis pointing up, and the x axis pointing "into the page." This coordinate system is used for the discussions of point source transmittance and edge response in subsequent sections.
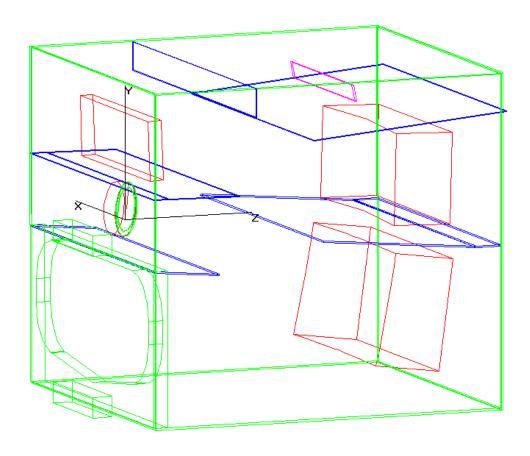
Figure 1 Isometric view of TracePro model of EO-1 telescope
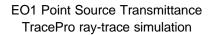
4.2   *TracePro Simulations and PST predictions*

In order to characterize the PST over the angles needed for the extended source integration over the Stray Radiation Scene, ray-traces were done using the TracePro model. Collimated light was simulated in a polar array of directions, with the pole of the array passing through the center of the six-degree-off-axis image surface. The polar angles simulated were 0.01, 0.1, 1, 2, 5, 10, 15, 20, and 25 degrees, while the azimuth angles were 0 through 315 degrees in 45-degree increments. This grid of 9 polar by 8 azimuth angles means a total of 72 simulations were done.

As expected, the stray light in all cases is dominated by mirror scatter, with M1 being the greatest contributor. The PST values resulting from the simulations are summarized in Figure 2. Also shown in Figure 2 are a simplified calculation of "unbaffled" PST as a point of reference and the equivalent PST due only to aperture diffraction. The unbaffled PST is what would occur if there were no baffles or instrument structure whatsoever. It was calculated from the mirror BRDFs using the formula

$$PST = \frac{p}{4F^2}(f_1 + f_2 + f_3 + f_4)$$

where F is the f-number of the optical system and f_1 through f_4 are the mirror BRDFs. An additional assumption implicit in this formula is that the BRDFs have a $1/\sin^2\theta$ dependence.

The predicted PST closely matches the earlier predicted PST at small off-field angles and shows the expected asymmetry at larger angles.
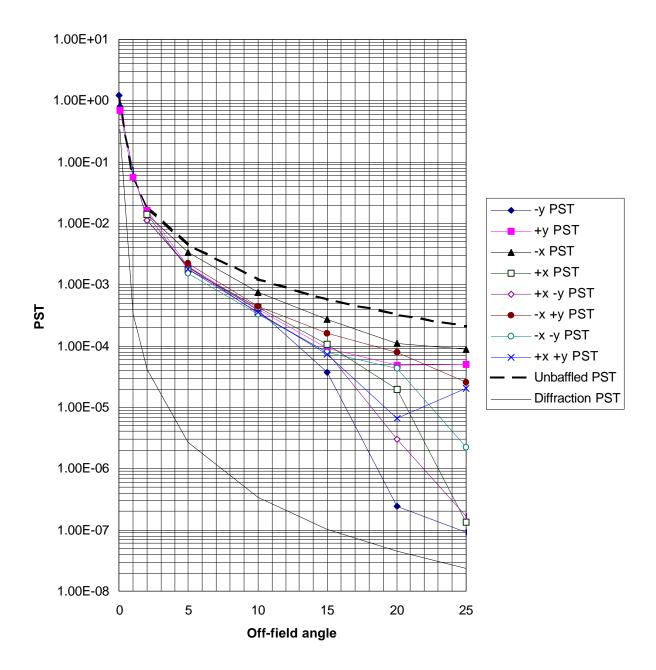
EO1 Point Source Transmittance
TracePro ray-trace simulation

Figure 2 PST predicted by TracePro for EO-1 band 3

There are some problematic angles for this telescope that, if it were not for the large amount of light scattered from M1, would emerge as stray light problems at large off-axis angles. One such case is illustrated in Figure 3. In this picture, light is incident at a y angle of +25 degrees and strikes M3 directly, from where is scatters directly toward the image of the detector. In a well-

baffled telescope, this light would be largely absorbed by the baffles, and only light scattered from baffles would reach M3. Ironically, M1 is completely shaded at this angle. This angle corresponds to the 25° point for the +y curve in Figure 2.
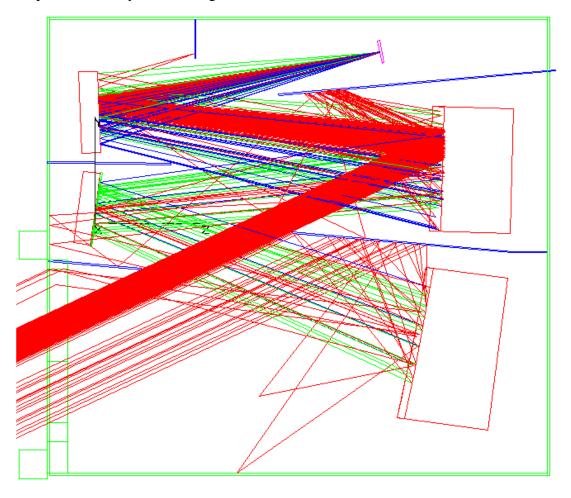

Figure 3 Light incident at y angle of +25 degrees reaches M3 directly.

4.3   Extended Source Integration

A special-purpose computer program was written to perform the integration over the annular source. The program performs a simple trapezoidal rule integration over the Stray Radiation Scene. The PST is interpolated between the calculated points using a semi-logarithmic interpolation - this is equivalent to drawing straight lines between the points on a semi-log graph of the PST as shown above. The resulting stray spectral radiance, calculated for Band 3 (a close match to 0.6328 um) was scaled to the other bands by a simple multiplicative factor. The results for all bands are summarized in the table below, along with the results calculated above using spreadsheet calculations. The results are in close agreement with the earlier results predicted by the spreadsheet calculation.

Table 4 Stray Spectral Radiance predicted by TracePro

Band	Previous results radiance	TracePro results radiance	Low gain spectral radiance	High gain spectral radiance	percent of lo gain	hi gain
PAN	1.20	**1.14**	23.5	15.63	4.83%	7.27%
1	4.03	**3.80**	28.57	19	13.29%	19.98%
2	2.64	**2.49**	29.13	19.37	8.55%	12.85%
3	1.58	**1.49**	22.5	14.96	6.62%	9.96%
4	0.65	**0.61**	22.5	14.96	2.72%	4.09%
5	0.043	**0.0409**	4.73	3.15	0.86%	1.30%
6 (cond 1)	2.0E-08	**1.86E-08**	0.0015	0.00077	0.0012%	0.0024%
6 (cond 2)	3.3E-08	**3.11E-08**	0.0015	0.00077	0.0021%	0.0040%
7	0.0094	**0.0089**	1.67	1.11	0.53%	0.80%

5.   Edge Response Degradation

In order to determine the effect of stray light on edge response, The PST calculated by TracePro was convolved with an edge scene function. A special purpose C++ program was written to perform this calculation. The calculation yields the relative intensity of light leaking out of the bright region and into the dark region. The edge response was calculated for four orientations of edge, with the bright region in: +x, -x, +y, and -y. The orientation of the bright region is that observed in image space. For example, light coming from the +y region is shown in Figure 3. The results are expressed in equivalent scene radiance, with scene radiance of unity. The results of the edge response calculations for Band 3 are shown in Figure 4 and Figure 5

We stress that this calculation was done for scattered light only, as directed by MIT Lincoln Lab. Aperture diffraction will cause additional leakage, especially at very small angles. Furthermore, the curves in Figure 5 should be considered as heuristic only. This is because the central portion of the PST (the image) is excluded from this calculation. The TracePro simulations only extend down to source angles of 0.01°. Even there, diffraction dominates the PST. The curves in Figure 5 then had to have the scene added in so that they would approach one at large angles. The shape of the curves and their relative height is accurate, but the absolute height is only a guess, obtained by assuming that they should approach one (without exceeding one, of course) at large angles. The same value, equal to 0.969, was added to all four curves to obtain the plot shown. An accurate calculation of the image portion of the PST would yield the correct curves without this estimated constant.

In hindsight, the leakage out of the bright region can be calculated as the complement of the leakage into the dark region. For example,

(Leakage out, edge scene = +y) = 1 - (Leakage in, edge scene = -y).

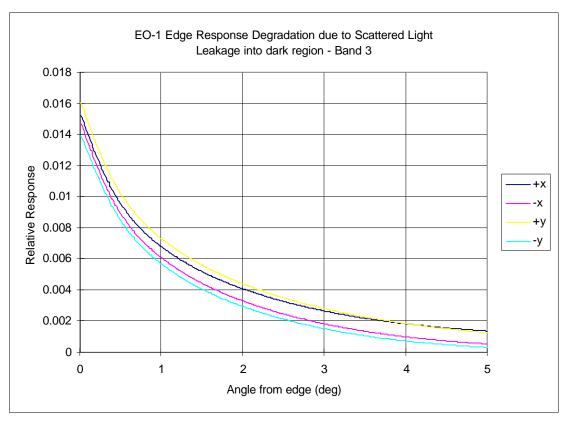This means that the curves in Figure 5 can be directly obtained from those in Figure 4.

EO-1 Edge Response Degradation due to Scattered Light
Leakage into dark region - Band 3

Figure 4 Edge response function - leakage into dark region due to scattered light only

EO-1 Edge Response Degradation due to Scattered Light
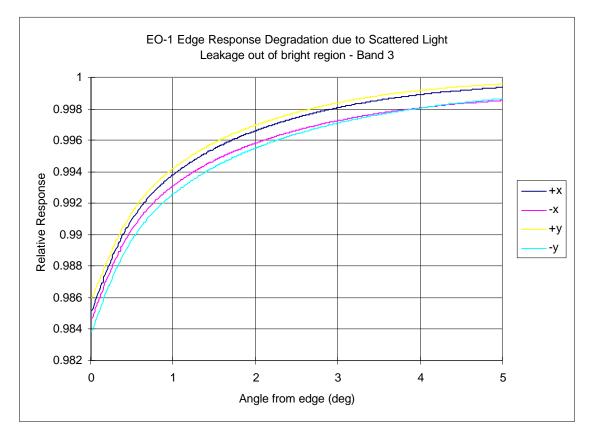Leakage out of bright region - Band 3

Figure 5 Edge response function - leakage out of bright region due to scattered light only

6.   Appendix A - ETM+ Stray Light Requirement

The ETM+ stray light requirement, taken from the LANDSAT 7 System Specification Revision K (July 1997) is restated here for completeness. Paragraph 3.7.8.1.16.5 of the specification begins:

"The response of an ETM+ detector channel to off-axis levels of stray radiation is defined as the change in detected signal that results when a radiance scene of specified level and annular solid angle FOV surrounds, and is centered on, an extended target FOV radiance scene that produced the baseline detected signal and on which the detector channel IFOV is centered."

The specification includes a table, Table 3-17, that defines the Extended FOV target and the Stray Radiation Scene for each wavelength band, as shown below.

From LANDSAT 7 System Specification Revision K, Table 3-17

Extended FOV Target			Stray Radiation Scene		
Spectral Band	FOV Diameter (μr)	Spectral Radiance Level (mW/cm^2-sr-μm)	Inner Annular Diameter (μr)	Annular Area (sr)	Spectral Radiance Level (mW/cm^2-sr-μm)
Panchromatic	256	2.285	768	0.63	44.05
1	256	4.000	768	0.63	57.32
2	256	3.000	768	0.63	55.17
3	256	2.167	768	0.63	48.31
4	256	1.357	768	0.63	35.72
5	256	0.400	768	0.63	12.97
7	256	0.170	768	0.63	5.93

For the Panchromatic band and bands 1-5 and 7, the Stray Radiation Scene is defined as having an inner diameter of 768 µr and an annular area of 0.63 sr. The Scene spectral radiance is different for each band. The Extended FOV Target has a diameter of 256 µr for all of the above bands and a different spectral radiance for each.

This description and accompanying table suggest an inner circular region of diameter 256 µr with low spectral radiance level (15x-20x lower than the scene radiance for most of the bands) and an outer annular region with inner diameter of 768 µr and outer radius of 0.436 rad. There is an annular region between these two in which the radiance is undefined. The inner diameter is 256 µr and the outer diameter is 768 µr. The calculations above were done by assuming that this intermediate region has the same radiance as the Extended FOV Target.

The specification paragraph continues with the following:

"The off-axis radiance of all channels for the ETM+ panchromatic and Spectral Bands 1, 2, 3, 4, 5 and 7 shall be less than 2% of the nominal full-scale signal level (Reference 3.7.8.1.7) for the extended target FOV scene size and radiance levels and the stray radiation scene annular size and radiance levels shown in Table 3-17."

The nominal full-scale signal level is given in Table 3-12 of the specification, Minimum Saturation Spectral Radiance, as shown below.

From LANDSAT 7 System Specification Revision K, Table 3-12

Spectral Band	Minimum Saturation Spectral Radiance (mW/cm^2-sr-μm)	
	Low Gain	High Gain
PAN	23.5	15.63
1	28.57	19.00
2	29.13	19.37
3	22.5	14.96
4	22.5	14.96
5	4.73	3.15
6(1)	340K	320K
7	1.67	1.11

(1) Band 6 specified as blackbody temperature with a lower scene temperature range of 200K for low gain and 260K for high gain.

The paragraph does not state which gain setting is to be used for this requirement. For this analysis, the stray spectral radiance has been calculated directly, and comparisons made to the saturation spectral radiance for both gain settings.
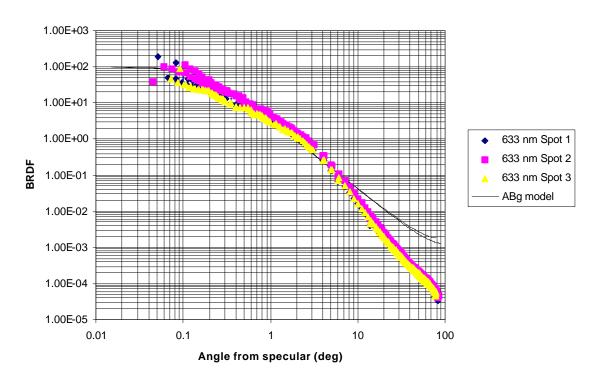
7.   Appendix B - Schmitt Measurement BRDF Data

The following graphs show the BRDF for the four EO-1 flight mirrors as measured by Schmitt Measurement Systems. The BRDF was measured at 0.6328 μm and at 3.39 μm. To create these curves, raw data was taken from the ASCII files containing the measured BRDF. The data was imported into MS Excel and graphed. After comparing with the signature data, also in ASCII files supplied by Schmitt, bad data was thrown out. This includes data in or near the specular beam, data at very large scattering angles, and data taken when the instrument was blocking the incident beam. Then the data taken for negative scattering angles was "folded back" so that it could be displayed on a log-log plot. This is why there are two sets of values for each plot symbol on the graphs. Finally, the TracePro ABg BRDF model was fitted to the data. it is displayed as a solid curve in each of the plots. For the F1 mirror, where there is significant variation in the BRDF for different "spots" on the mirror, a representative curve was derived. Since M1 scatter dominates the PST, this is a minor detail. The A, B, and g coefficients used are shown in Table 5 below.
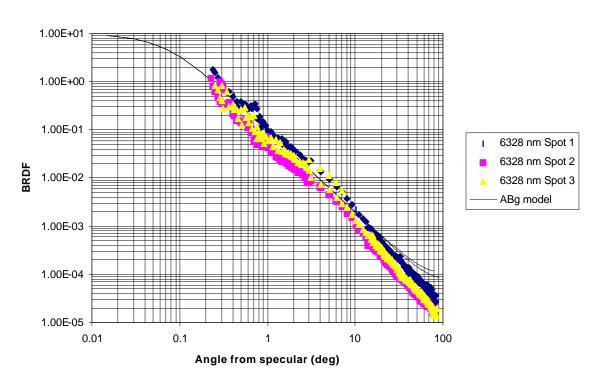
Table 5 ABg models used in TracePro simulation for 0.6328 um

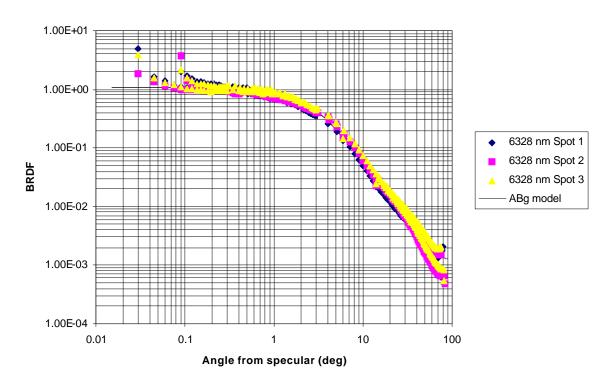|	M1	M2	M3	F1
A	1.50E-03	1.00E-04	1.50E-03	5.00E-04
B	1.50E-05	1.00E-05	1.40E-03	4.00E-03
g	1.9	1.7	2.1	1.6

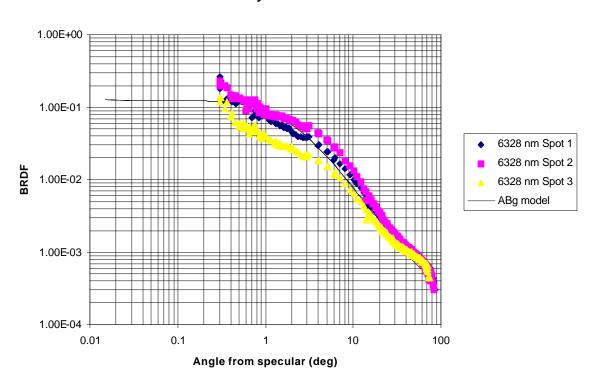**BRDF of M1 at 633 nm**
Measured by Schmitt Measurement

BRDF of M2 at 6328 nm
Measured by Schmitt Measurement

BRDF of M3 at 6328 nm
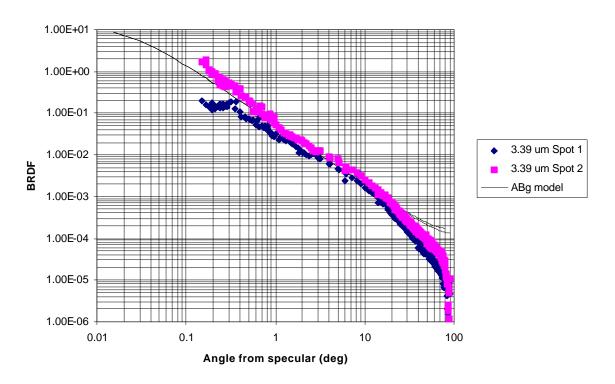**Measured by Schmitt Measurement**

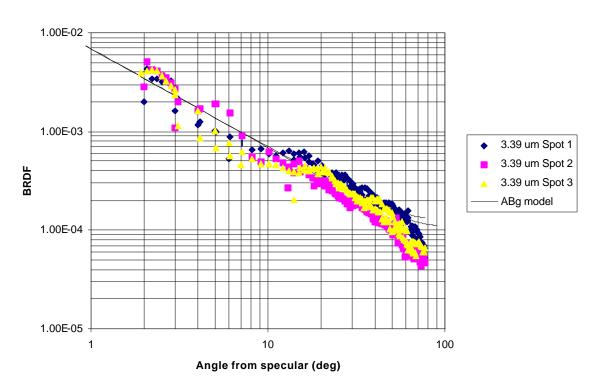**BRDF of F1 at 6328 nm**
Measured by Schmitt Measurement

BRDF of M1 at 3.39 um
Measured by Schmitt Measurement

BRDF of M2 at 3.39 um
Measured by Schmitt Measurement

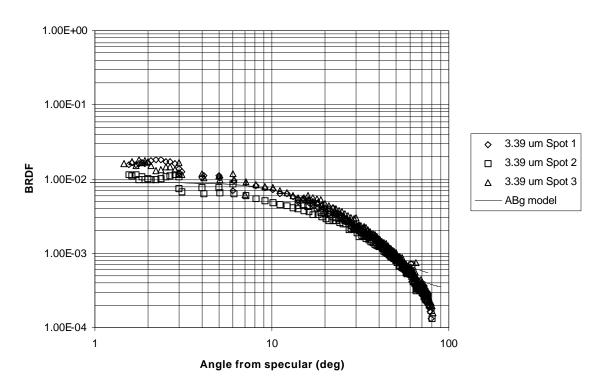**BRDF of M3 at 3.39 um**
Measured by Schmitt Measurement

BRDF of F1 at 3.39 um
Measured by Schmitt Measurement